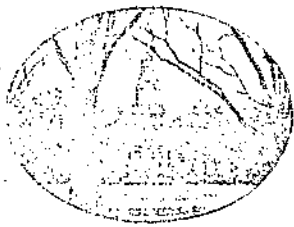


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Prepared by

Paul D. Feldman and Wm. G. Fastie

Submitted in response to
DRD #DM-024T

Baltimore, Maryland 21218

27 September 1971

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DEPARTMENT OF PHYSICS
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Subject: Scientific Data Reduction and Analysis Plan - PI Services,
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Enclosure: (1) The Subject Plan

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Wm. G. Fastie

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SCIENTIFIC DATA REDUCTION AND
ANALYSIS PLAN - PI SERVICES

Contract NAS 9-11528 - Task I

Prepared by

Paul D. Feldman and Wm. G. Fastie

27 September 1971

Submitted in response to
DRD #DM-024T

Physics Department
The Johns Hopkins University
Baltimore, Maryland 21218

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Appendix. Special Report

Apollo 17 UVS Scientific Data Reduction and Analysis Plan

I. Introduction

This plan comprises two parts. The first concerns the real-time data display to be provided by MSC during the mission. The prime goal here is to assess the operation of the UVS and to identify any problem areas that could be corrected during the mission. In addition, it is desirable to identify any possible observations of unusual scientific interest in order to repeat these observations at a later point in the mission, or to modify the time line with respect to the operating modes of the UVS. The second part of the plan discusses the more extensive post-flight analysis of the data in terms of the scientific objectives of this experiment.

In both parts of the plan, we are guided by our experience in handling the data obtained with a preprototype UVS experiment on board an Aerobee 350 sounding rocket launched June 10, 1971 at Wallops Island, Va. The details of the rocket payload have been described in a separate PI special report "Rocket Flight Performance of a Preprototype Apollo 17 UV Spectrometer - S-169," July 3, 1971, which is an appendix of this report.

II. Description of UVS Experiment and its Operating Modes

The purpose of the UVS experiment is to measure the UV light which may be emitted by atoms in the lunar atmosphere. Its secondary purposes are to measure the lunar UV albedo, dark side fluorescence, UV emissions from the LEM engines, scattering by ice clouds around the spacecraft, UV emissions from the galaxy and UV emissions from the extremities of the earth's atmosphere during TEC.

Although the prime operating time of the UVS is limited to a few hours in each of four operating modes, the instrument is designed to operate continuously except during RCS burn, the early phases of lunar launch propulsion, and when the UVS field of view is close to the sun direction. We anticipate that the instrument will be operated whenever possible in order to maximize the prime data and to accomplish the secondary objectives. We also anticipate that most of the UVS data will be available in real time in order that we can evaluate the degree of accomplishment of the many experimental objectives. Since the UVS employs only 1 out of 400 words in the scientific data stream, it appears that this requirement is not excessive.

The UVS has four operating modes as follows:

Mode I - Space craft pointed in +X direction (i. e., nose forward). SIM Bay axis automatically controlled to remain moon centered.

Mode II - Spacecraft pointed in $-X$ direction. SIM
Bay axis moon centered as in I.

Mode III- Spacecraft held in fixed galactic coordinates.

Mode IV -Trans Earth Coast - Spacecraft in solar barbecue
mode

The scientific output of the UV spectrometer consists of photoelectrons, the output rate of which determines the brightness of the observed UV radiation. Since the data stream is phased with respect to the spectral scan, the wavelength of the light emission producing the photoelectrons is known. Internal electronics accumulate the photoelectrons for 0.1 seconds. The scientific data is transmitted as a single word every tenth second.

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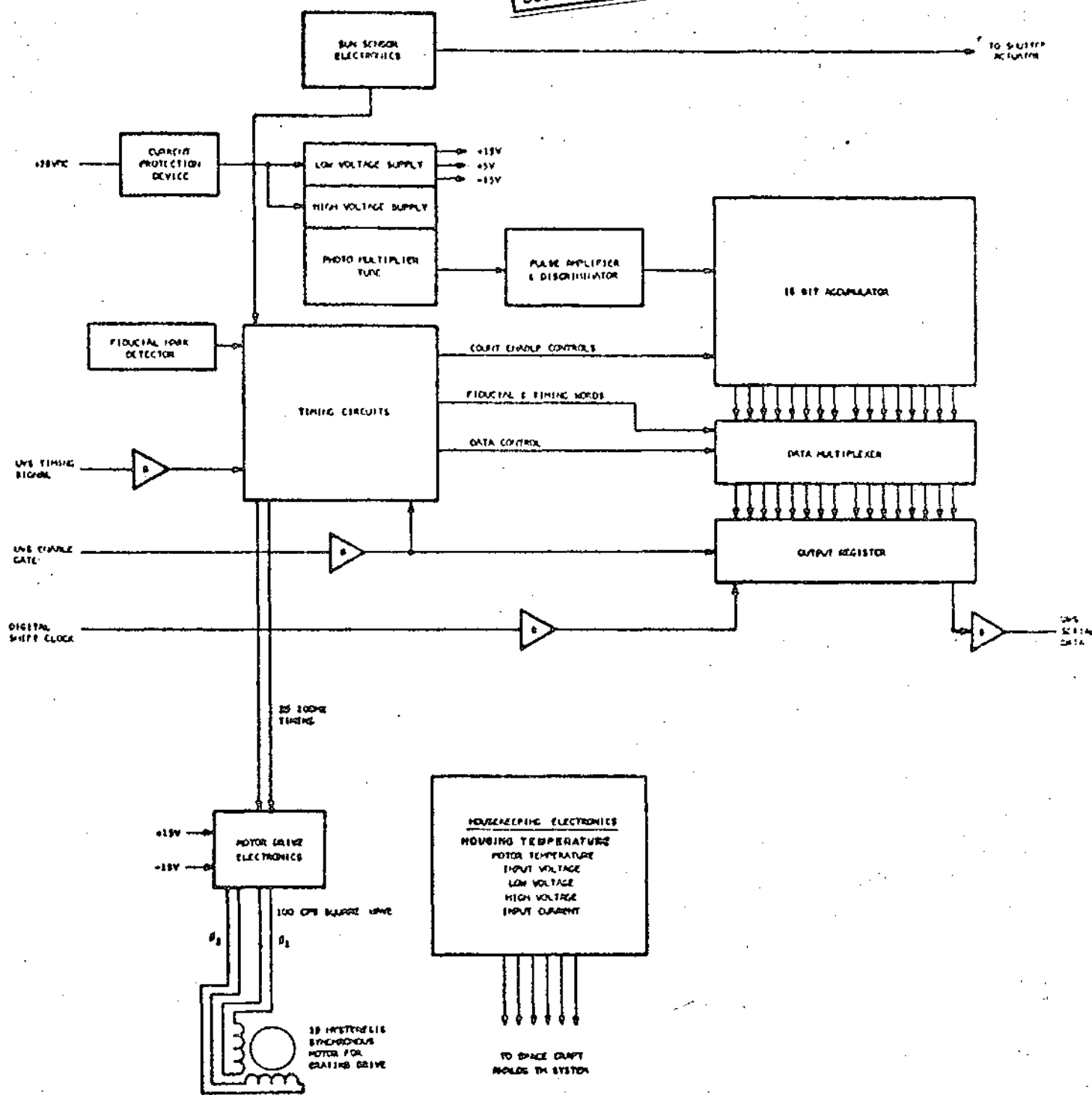


Fig. 1. BLOCK DIAGRAM FOR UV SPECTROMETER

III. UVS Data Format

In order to better understand the data requirements, a brief description of the UVS data format is in order. A complete spectral scan consists of 120 (± 1) 16 bit data words every 12 seconds, of which the first five are special "fiducial" words, and the remaining 115 are "true" data words. The fiducial word generator is triggered during the flyback of the spectrometer grating to indicate the beginning of each new spectral scan. In addition, the fiducial circuitry is synchronized to the motor drive to ensure that a given data word will correspond to the same wavelength interval in different spectral scans. In this way, we ensure that many individual scans may be added together, to improve the signal-to-noise ratio, without introducing any distortion of the UV spectrum. In the event of a failure of the fiducial circuitry, the data analysis program must be altered, as will be described below, but the scientific data can still be retrieved. The fiducial words also contain timing information about the UVS scan rate. A block diagram of the UVS electronics is shown in Fig. 1.

Both fiducial and true data words are 16 bit words, generated every 0.1 sec. Thus, 12 seconds are required for a complete spectral scan. The word format is shown in Table I. Each data word is simply the number of counts received in the previous 0.1 sec interval, expressed

Table I
Word Format for UVS Digital Data

| <u>Word No.</u> | <u>Name</u> | <u>Bit Pattern</u> | <u>Comments</u> |
|-----------------|-----------------|---|---|
| 1 | Fiducial Mark 1 | 0101011111111111 | Generated by Fiducial Mark 1 at the completion of the 12 sec. scan. |
| 2 | " " | 1010100000000000 | |
| 3 | Timing Word | XXXXXXXXXXXXXXXXYZ | |
| 4 | Fiducial Mark 2 | 1010100000000000 | Generated by Fiducial Mark 2 at the initiation of a new scan |
| 5 | Fiducial Mark 2 | 0101011111111111 | |
| 6 | λ_1 | Binary data representing the number of pulses detected at each wave- length n. Typical format is XXXXXXXXXXXXXXXXXX <div style="display: flex; justify-content: space-between; width: 100%;"> <div style="text-align: center;"> \uparrow Least Significant Bit </div> <div style="text-align: center;"> \uparrow Most Significant Bit </div> </div> | |
| 7 | λ_2 | | |
| 8 | λ_3 | | |
| 9 | λ_4 | | |
| 120 | λ_{115} | | |

as a pure binary number. Typical dark counting rates are ~ 2 counts/sec, while the maximum count expressable with 16 bits is 65000 counts in 0.1 secs. Actually, for high counting rates (> 100 kHz), the dead response time of the pulse counting circuitry produces a non-linear relationship between measured counts and the number of incident photons, and it is possible to measure real pulse rates as high as 2 MHz with reasonable accuracy. Both extremes of this large dynamic range will be encountered during the mission (e. g. very high counting rates when looking directly at the lunar surface; very low counting rates when examining the lunar atmosphere) and the real time data display must be designed to adequately handle both extremes.

In addition to the prime data, there are also 6 housekeeping channels which are multiplexed through the spacecraft's main A/D system. These are listed in Table II.

Table II

| <u>TM Function</u> | <u>Range</u> | <u>Sensitivity</u> | <u>Accuracy</u> |
|-------------------------------------|---------------|--------------------|-----------------|
| UVS Housing Temp. | -20° to +80°C | 20°C/V | 2% |
| UVS Motor Temp. | -20° to +80°C | 20°C/V | 2% |
| UVS Input Volt. | 0 to 40V DC | 8V/V | 4% |
| UVS Input Current | 0 to +0.5 amp | .1 amp/V | 4% |
| UVS Photomultiplier High Voltage | 0 to 4000V DC | 800V/V | 2% |
| UVS Regulated Volt. | 0 to 10V DC | 2V/V | 2% |

IV. Real-Time Data Display

The real-time data display serves several purposes:

- 1.) It permits assessment of the performance of the UVS. In the event of difficulty or malfunction, troubleshooting is possible.
- 2.) It permits the determination of any interference between experiments on board, and if so, allows changes that would reduce this interference.
- 3.) It provides a first look at the scientific questions underlying the experiment. Unusual or unexpected preliminary findings may warrant an alteration of the UVS time line and operating mode in order to further investigate these results.
- 4.) It provides an opportunity to respond quickly to the astronaut with respect to his activity (for example, changes in spacecraft altitude, gaseous and liquid exhausts, etc.)

Two data displays are requested, both hard-copy, one numeric, the other graphic.

- 1.) Printed output. A sequential listing of the data, in decimal representation, and in blocks of 120 words, on a small printer will provide quantitative information about the performance of the UVS. It is not necessary for the system providing this data to recognize the fiducial sequence; this can be best done visually.

9 SEP 71

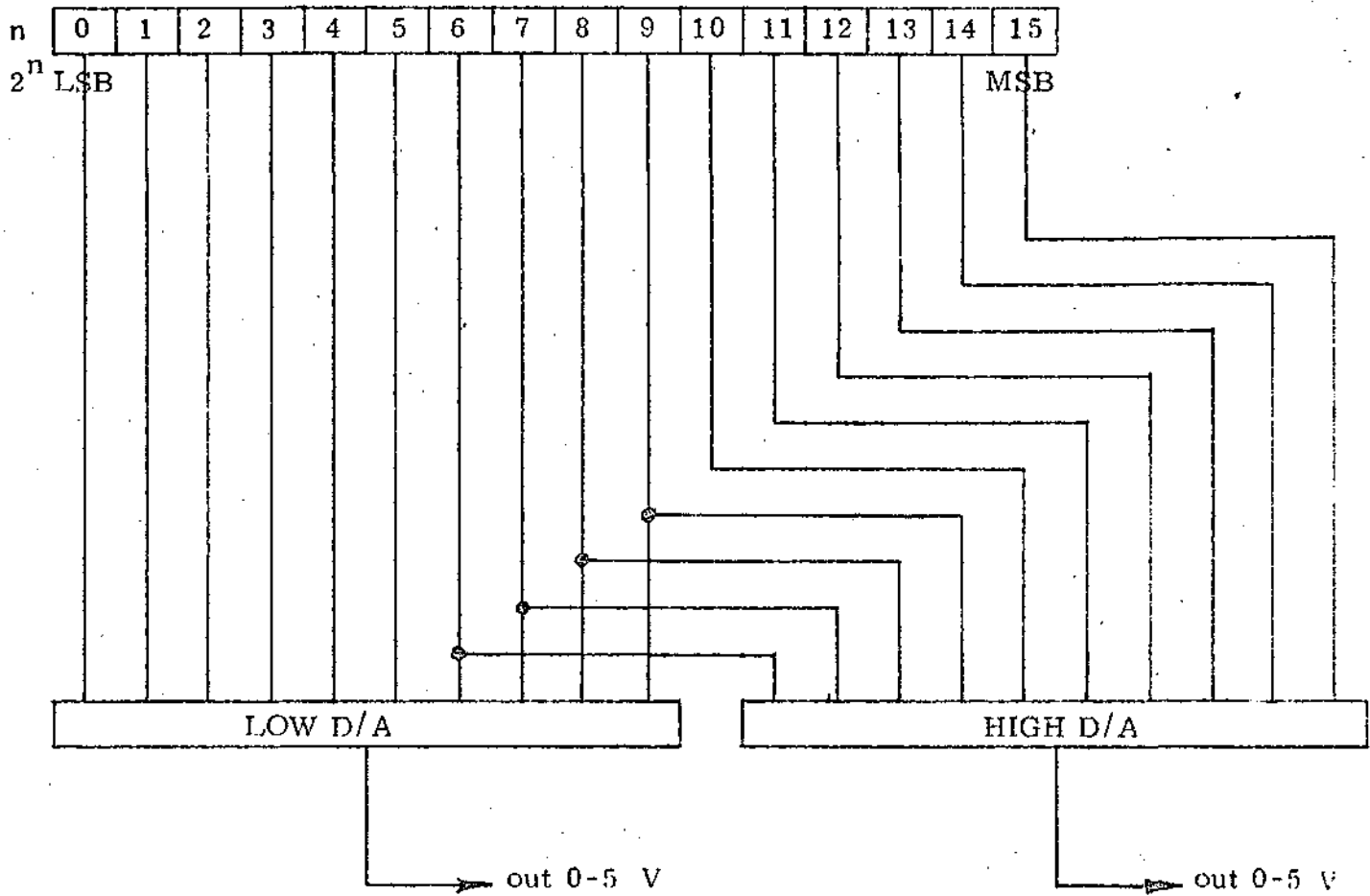


Fig. 2

It is essential that this information be obtained in hard-copy format (an instantaneous TV display is not acceptable) so that the data may be correlated with the view direction of the UVS, and so that preliminary manual spectral summations can be performed. For example we may wish to manually scan 20 successive spectra.

- 2.) Graphic Output. Because of the large dynamic range of the output, two channels of analog output are required. This was accomplished on the rocket experiment by means of two 10-bit digital-to-analog converters as shown in Fig. 2. The chart recorder should have 2 channels with a minimum 5 cm full-scale deflection and a chart speed of ~ 1 cm/sec. It is important to recognize that the graphic display complements the printer output, rather than duplicates it. For example, proper focus of the spectrometer can be checked by examining the spectral line shape of a known emission feature (e. g. H I Ly α) from the graphic display. A weak repetitive spectral feature is more easily detected on a graphic display whereas the determination of the dark counting rate and manual spectral summation of successive scans are best done with the aid of the numeric data.

In addition to the spectrometer data and the associated housekeeping information, position and altitude data of the UVS are required. However,

housekeeping information is probably only needed infrequently, perhaps 5 times per hour. Likewise, positional attitude data need only be updated infrequently if nominal time line information is available. For example, if the spacecraft is in Mode I or Mode II, and spacecraft attitude is nominal, spacecraft lunar ephemeris information once per hour is adequate.

V. Post Flight Data Reduction

- 1-1. The post-flight analysis of the Apollo 17 UVS data will be performed at JHU. The campus computer facility contains an IBM 7094 computer and has provision for graphic display of the data. Large blocks of computer-time are available outside of the prime hours of use (12-8 a.m. and all day Sunday). While other, faster computers are available in other divisions of the University, processing time will be determined by input-output operations, rather than computation speed, so there is no need to go to the faster computer. All of the data processing will be performed at our campus facilities.
- 1-2. The tape formats should be compatible with the 36 bit word of the IBM 7094. The postflight trajectory parameters (MSC Internal Note 70-FM-21) are generated by a UNIVAC 1108 which is compatible with the IBM 7094. At present the IBM 7094 tape drives will accept only 7 track 556 bpi tapes, but it is anticipated that 800 bpi tapes will be acceptable by the time of the mission.
- 1-3. There should be separate tapes containing the data as follows:
 - a) UVS data
 - b) Postflight trajectory parameters
 - c) Housekeeping informationAll three tapes will contain GET_s and GMT_c in order to correlate the data between tapes.

- 1-4. UVS data and trajectory parameters are required only for times during which the UVS is operating.
- 1-5. The UVS data tape should be blocked in integer multiples of 120 data words (the UVS scan length). The data words may be packed, two 16 bit words in one 6 character (36 bit) tape word. The blank bits should be located as shown in Fig. 3.

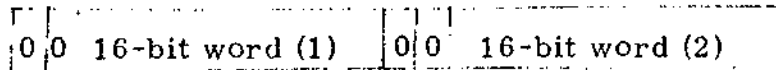


Fig. 3

In addition, each block should contain time words related to the first data point of the block. If possible, each block of data should begin with the 5 fiducial words of a particular scan.

- 2.1 The computer analysis of UVS data is dependent on the UVS mode of operation. We consider separately the two cases of high and low counting rates.
- 2.2 In the case of lunar albedo or galactic γ measurements, we have counting rates sufficiently high to permit analysis of individual spectral scans. Moreover, the observation of known spectral features gives us a check on the performance of the UVS as described in the section on real-time data display.

The analysis begins with the separation of a single scan from the data block and the determinations (from one of the fiducial words)

of the exact length of time of the scan. For a particular spectral line or group of lines a synthetic spectrum is calculated. The following parameters are fixed for the calculation:

- a) UVS scan time.
- b) Wavelengths of observed line or lines.
- c) Spectral width (and shape) of these lines.
- d) Dead-time of the pulse counting electrons.
- e) Relative response of the UVS at the different wavelengths (determined from calibration).

The other parameters which enter the calculation are either approximately known or unknown and are determined from some kind of least squares fit of the data to the synthetic spectrum:

- f) Line intensity (brightness).
- g) Spectral slit function.
- h) Wavelength at $t = 0$ in each scan.

Items (g) and (h), while possibly different from their pre-flight calibration values, should remain roughly constant during the entire mission. In addition it may be necessary to allow for radiation scattered from the grating in order to best fit the synthetic spectrum. This will have been determined during instrument calibration. A sample synthetic spectrum is shown in Fig. 4 for Ly α (1216A) using the cam program for the

9 SEP 71

16.

$\lambda_0 = 1173 \text{ \AA}$
 $t = 1.6 \mu\text{s}$

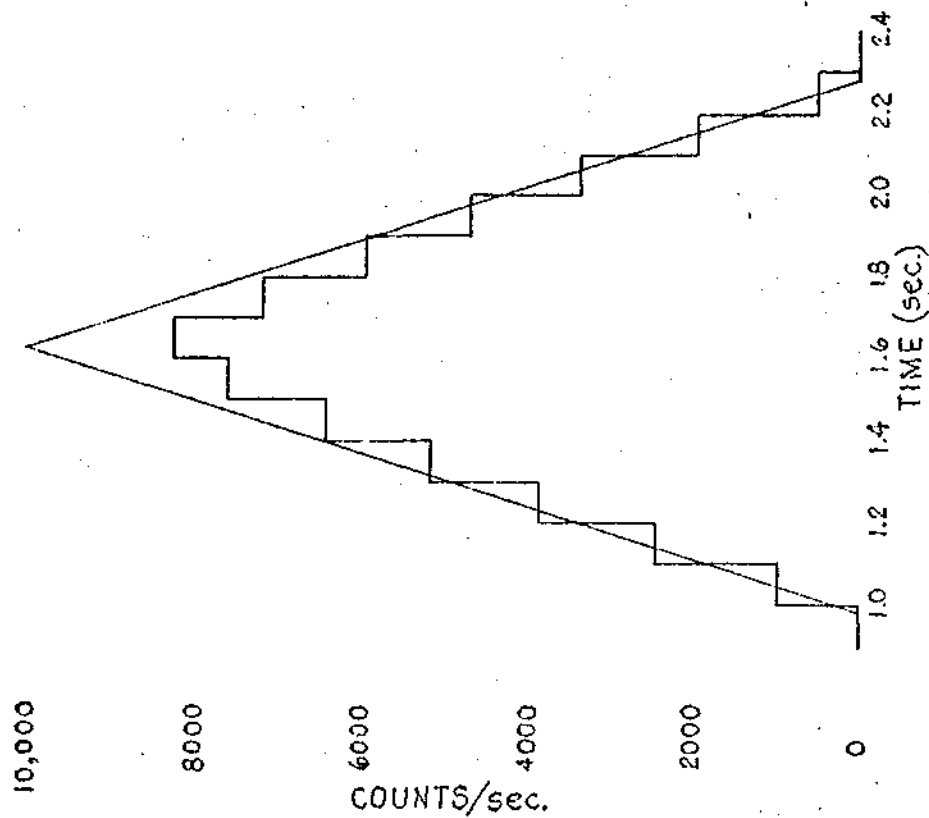


Fig. 4b

$\lambda_0 = 1172 \text{ \AA}$
 $t = 1.6 \mu\text{s}$

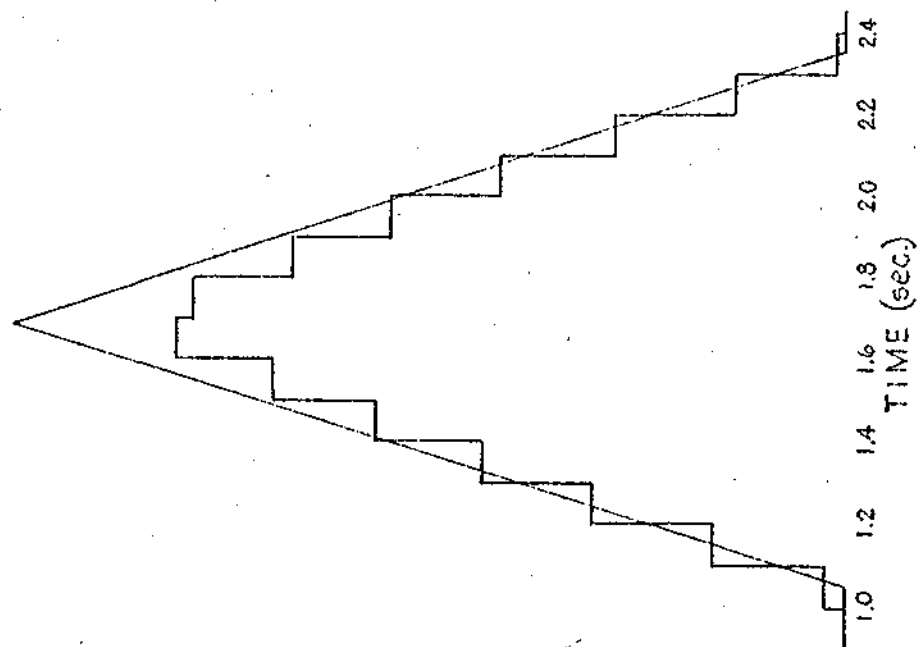


Fig. 4a

Fig. 4

Aerobee 350 Preprototype UVS with two possible values of parameter (h). Fig. 7 of the Appendix shows some data from the rocket flight.

2.3 The output from the computer analysis will consist of line printer output and plotter display. The line printer output will contain:

- a) UVS scan number and time. Mode of operation.
- b) Position and attitude information.
- c) Best-fit values of the adjustable parameters (f-h in 2.2) and a figure of merit for the goodness-of-fit derived from the statistical analysis.
- d) Wavelengths and intensities (converted from counting rates into Rayleighs using the calibration data) of all of the observed lines, and the uncertainty in the intensity values. The main sources of uncertainty are the uncertainties in intensity and wavelength calibration and the statistical fluctuations in photon counting rates.

The plotter display will show, for each scan, the raw data, the derived spectral intensities and the synthetic spectrum calculated from these intensities.

2.4 In the case of low counting rate data, such as obtained when observing the lunar atmosphere, analysis proceeds in the same way as in 2.2, with two changes:

- a) The data from several UVS scans will be combined to improve the signal-to-noise ratio. This may be done in several ways. For instance, the data from successive UVS scans may be added. In this way, we combine the photon counting rates observed over a wide range of altitudes in the lunar atmosphere. In addition, it is possible to add such data taken over many orbits of the CSM to further enhance the S/N ratio. The fiducial circuitry assures that a given word in different UVS scans will contain the number of counts for a given spectral interval, and that the process of data summation will not distort the resulting UV spectrum. This aspect of the data analysis is especially important to the determination of the density of the UV emitting constituents (H, Xe, Ar) of the lunar atmosphere, since the highest possible signal-to-noise ratio is required for optimum results.

Another problem of prime importance is the determination of the scale height (distribution with altitude) of the atmospheric components. This is obtained from an analysis of observed spectral intensity as a function of the height above the moon's limb or the shadow height above the terminator that the UVS was pointing at during the measurement. Again, summations of individual scans will be necessary to enhance the S/N ratio, only in this case we can

combine the data only from those scans looking the same height above the limb or terminator. This information will be derived from the post-flight trajectory parameters tape.

- b) When no line is observed where expected, the statistical analysis must determine the maximum possible intensity consistent with the observed noise background level.

2.5 The format for computer output is the same as in 2.3 except for the inclusion of a listing of all of the scans used in the summing of the data.

In addition, for the case of 2.4(b), we also list upper limits on a given line consistent with one, two and three standard deviation from the background count level.

2.6 In addition to spectral information, the computer output will include listings or plots of intensity at a given wavelength as a function of positional parameters such as distance from lunar limb or galactic coordinates.

2.7 The basic data reduction routines will be derived from similar computer routines used in the analysis of the Aerobee 350 UVS data. Data from the rocket flight and the calibration equipment will be formatted to simulate the Apollo tape formats, and used to check out the analysis programs.

3.1 In the case of a failure of the fiducial circuitry, the UVS data can be retrieved without too serious a loss in quality, but at the cost of

additional data processing. In the fail-safe operation, loss of the fiducial synch pulse or an unexpected continual synch pulse will result in an unblocked data stream without the five fiducial words at the beginning of each scan. Position in wavelength would then have to be determined from the observation of H Ly α radiation, either galactic or lunar surface reflected sunlight. Scan length is similarly determined from the time between the successive observations of the same line.

The most serious degradations arise from the shift of wavelength intervals in successive UVS scans since the fiducial synch pulse also serves to initialize the counting circuits' timing. Thus, in spectra obtained by summing several individual scans, there may be an additional contribution to the observed line width by an amount equal to the wavelength scanned in one counting interval (0.1 sec). During the slow scan periods, this is 1.7 Å, compared to a spectral slit width of 11Å, and is tolerable. However, during the rapid scan periods, the additional width is 7Å, which might make identification of weak features in this range extremely difficult.

There would be no effect on the determination of spectral intensities due to the loss of fiducial.

- 4.1 We are preparing a digital tape with several excerpts of the preprototype UVS data obtained in the earth's ionosphere. (See Appendix.) The data have been modified to provide a fiducial word identical to the Apollo UVS format. There is one record per spectral scan, blocked as follows:

| | |
|------------|---|
| Word 1 | Green Word (generated by 7094 system) |
| Word 2 | Time of beginning of scan (UT) |
| Words 3-62 | Data words, blocked 2 to a word as in Fig. 3 |

We request that our tape be used to produce a tape identical to those we will receive from the Apollo 17 flight. We will then be in a position to test our programs prior to flight. The synthetic tape should also be invaluable at MSC in proving in the real time display equipment. To support this activity, we will provide a two channel strip chart record of the preprototype data, giving high and low outputs (10 most significant and 10 least significant bits).

APPENDIX

SPECIAL REPORT

ROCKET FLIGHT PERFORMANCE OF A
PREPROTOTYPE APOLLO 17 UV SPECTROMETER - S-169

Without Appendices A, B and C

A P P E N D I X

SPECIAL REPORT

ROCKET FLIGHT PERFORMANCE OF A
PREPROTOTYPE APOLLO 17 UV SPECTROMETER - S-169

Submitted by

Wm. G. Fastie
Principal Investigator

The Johns Hopkins University
Department of Physics
Baltimore, Maryland 21218

NASA/MSC Contract NAS 9-11528

Task I - Principal Investigator Services

July 3, 1971

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I. Introduction

The purpose of this special report is to describe in detail the design, construction, testing, calibration, flight performance and flight data of an Ebert ultraviolet spectrometer which is an accurate representation of the conceptual design of the Apollo 17 UV spectrometer. The instrument was flown in an Aerobee 350 rocket from Wallops Island, Va., at 7:10 p.m. EDT on June 10, 1971 to an altitude of 328 km with a solar elevation angle of about 11° . The funds to provide the instrumentation were part of a special supplement to NASA grant NGR-21-001-001 with Johns Hopkins University for which the writer is principal investigator.

This report is presented in advance of the critical design review of the Apollo 17 UVS for the purpose of demonstrating the soundness of the optical-mechanical-electronic designs of the Apollo 17 UVS which are to be presented at the CDR.

In particular, the rocket experiment has provided the following technical information which will be invaluable to the Apollo 17 UVS experiment:

1. Laboratory and in-flight light scattering measurements with an entrance baffle substantially identical to the Apollo 17 UVS baffle.
2. Experimental proof that the novel exit slit mirrors will provide increased output signal with no loss of spectral resolution.
3. Experience with the unified slit plate assembly which includes the wavelength drive system, diffraction grating mount,

wavelength fiducial system, exit slit mirror assembly and detector electronics.

4. Demonstration that the Vacuum Optical Bench at Goddard Space Flight Center can provide a significant absolute calibration check point without modification to the VOB.

5. Experimental proof that the proposed pulse counting electronic circuitry provides spectral information limited only by statistical fluctuations in the UV photon flux.

6. Experimental proof that the proposed sensitivity of 50 photoelectrons per second per Rayleigh for the Apollo 17 UVS can be achieved.

7. Flight data at the top of the earth's atmosphere showing weak emission features in the intensity range anticipated from the Apollo 17 experiment. This information will be extremely useful in planning the real time data presentation and in programming lunar data for scientific analysis.

II. Description of Preprototype Spectrometer

The conceptual design of the optical-mechanical system is shown in Fig. 1 in an exploded isometric sketch. Fig. 1 was included in our response to the RFP as an end product of the preliminary design study contract (NAS 9-10292) and engineering design study contract (NAS 9-11288) which preceded the current combined hardware and principal investigator services contract. A block diagram of the electronic

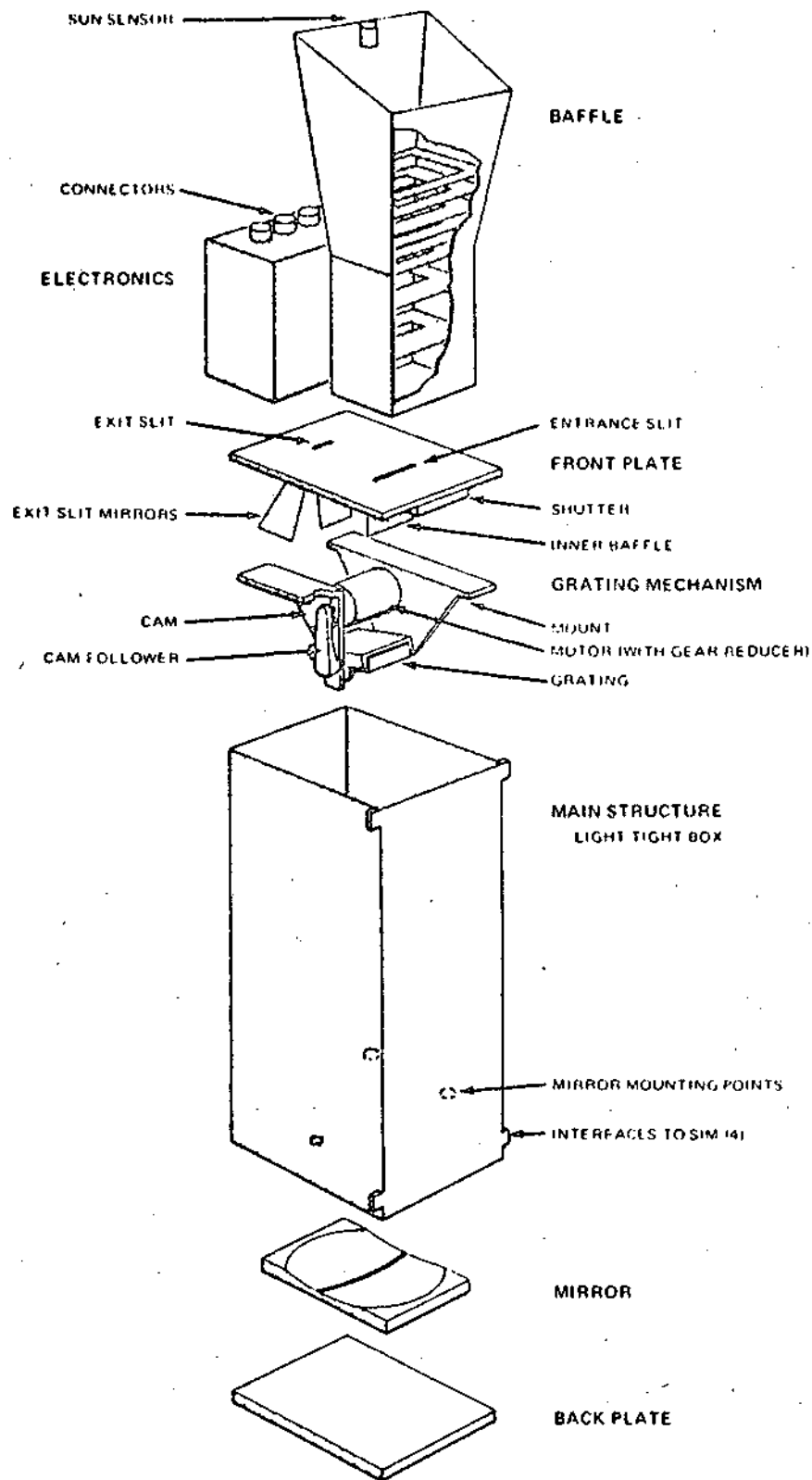


Fig. 1 UVS EXPLODED VIEW

circuitry is shown in Fig. 2 as it existed at the end of the preliminary studies. The preprototype instrument was designed and constructed to conform to the above design criteria.

Appendix A is a set of sketches of the mechanical-optical system as it was constructed. Appendix B is a set of photographs of the instrument parts, subassemblies and rocket installation.

For purposes of comparison, the major differences between the preprototype spectrometer and the design to be presented at the critical design review are as follows:

1. The main housing was a magnesium casting which was cut out in places to accommodate the Apollo UVS slit geometry. It interfaced with the rocket at four points at the Ebert mirror end of the housing.
2. The Ebert mirror was slightly undersize.
3. The cam drive motor was a commercial Weston synchro-servo motor requiring 3 watts.
4. A standard grating blank 110 mm x 110 mm x 16 mm thick was used. The grating was from the only existing B and L master which will be used as a backup master for the Apollo UVS in the event B and L cannot produce a satisfactory new master.
5. No external thermal insulation was used.
6. The EMR 542G photomultiplier tube had a lithium fluoride window instead of the magnesium fluoride window specified for Apollo.

The high voltage power supply was a separate unit mounted next to the PM tube rather than integrated with the PM tube as is proposed for the Apollo 17 instruments.

7. The electronic units were standard components purchased from SpaCom Electronics Company but operated in a manner substantially identical to the Apollo 17 electronic system shown in Fig. 2, as proposed by Applied Physics Laboratory (Mr. G. Donald Wagner). The system output was made compatible with Aerobee FM-FM telemetry, but was tape recorded in a format which will make it possible to produce a magnetic tape identical to the Apollo data tapes. A block diagram of the preprototype electronic system is shown in Fig. 3. Figs. 3a to 3d show detailed circuitry for the electronic components shown in Fig. 3.

The regulated low voltage power supplies to operate the electronic system were also supplied by SpaCom. These supplies were in common use with other experiments aboard the rocket.

III. Preflight Calibration

The following optical tests were made on the mirrors, grating and photomultiplier tube:

1. Two Ebert mirrors were coated with Al-MgF at the Goddard Space Flight Center coating facility (Dr. John Magnus) and measured by them to have reflectivity in the range 80 to 85% at 1216 Å. These values were confirmed by measurements in our laboratory.

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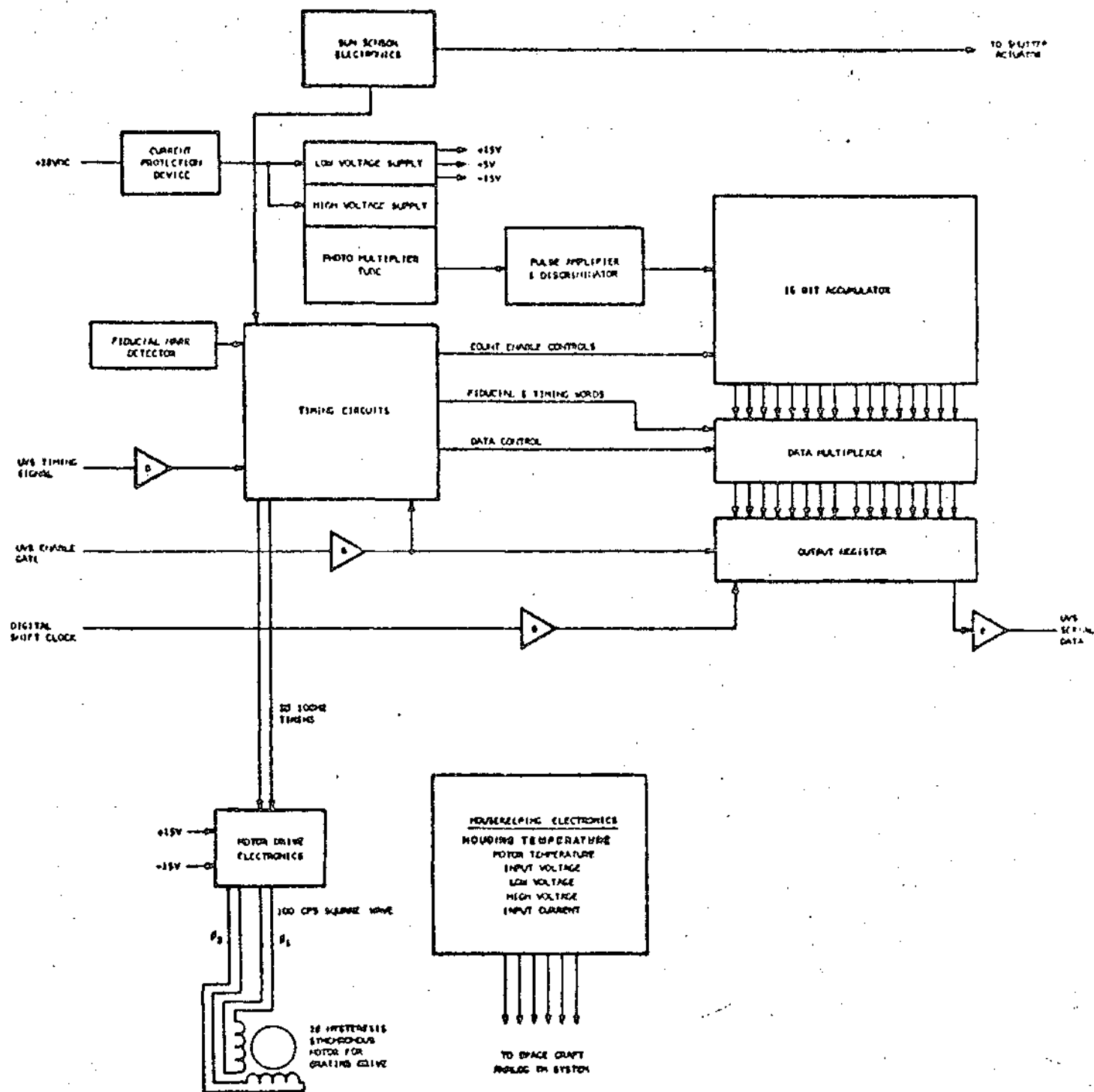


Fig. 2 BLOCK DIAGRAM FOR UV SPECTROMETER

AEROBEE 17.11

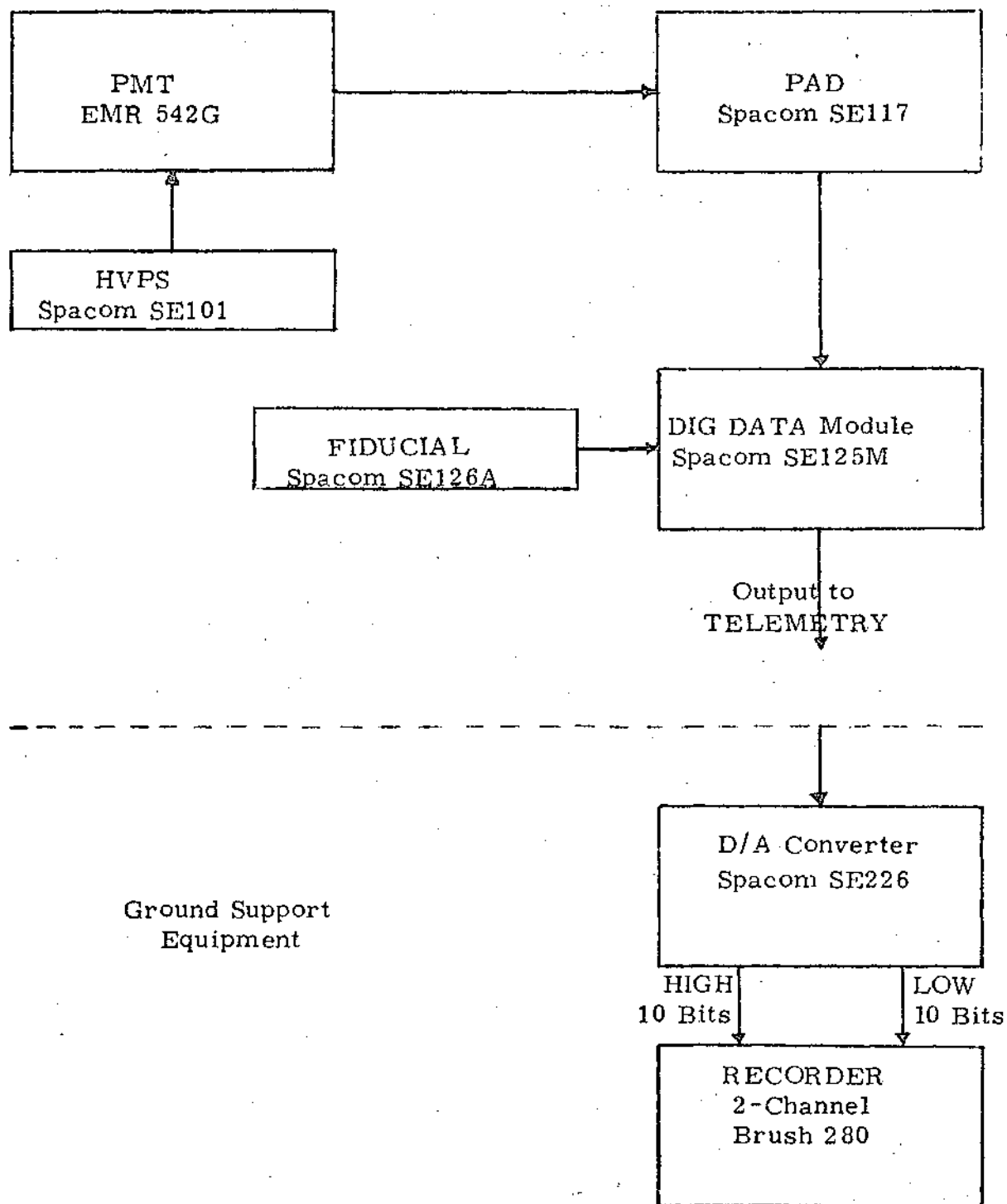
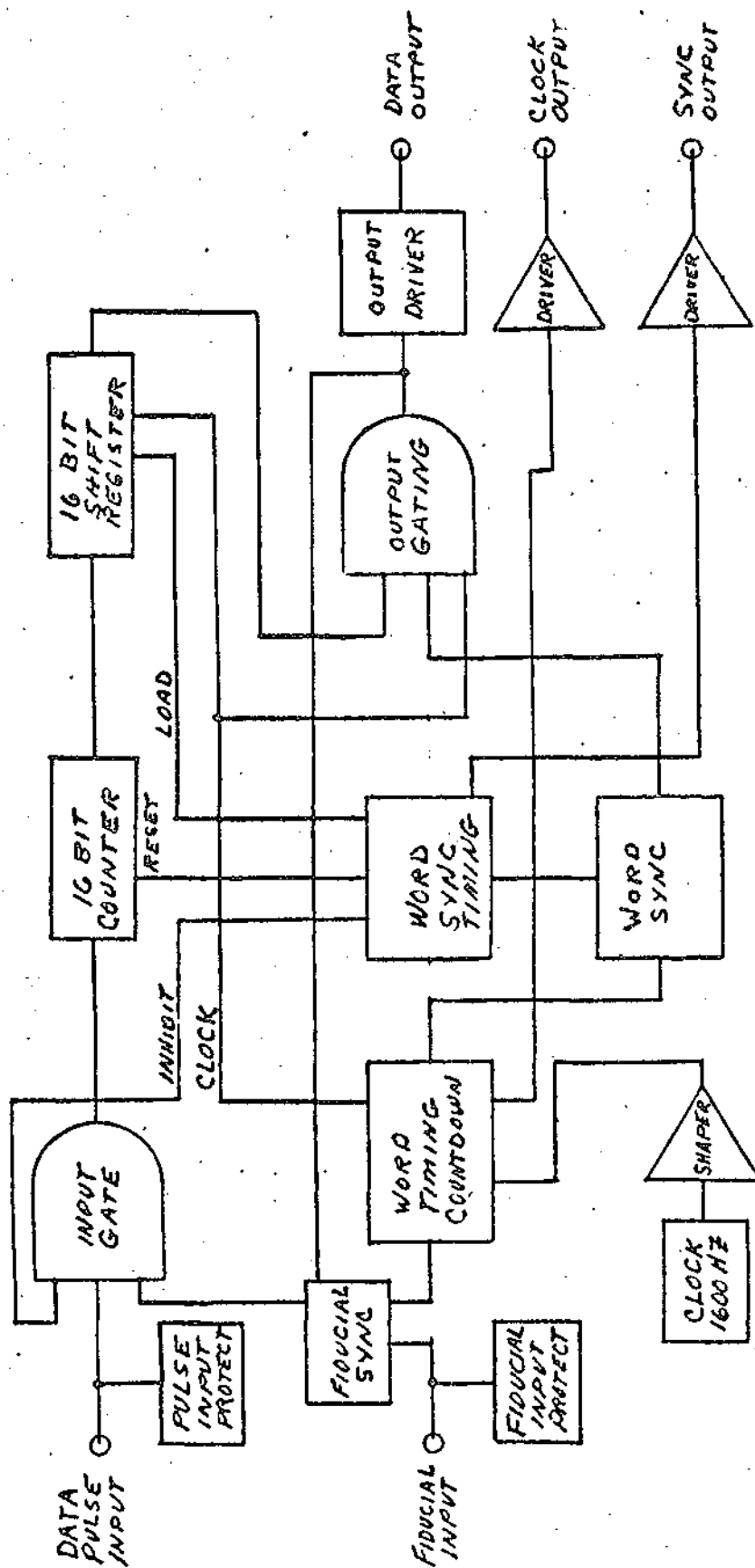


Fig. 3. Preprototype Electronic System



| | | |
|----------------------------|---------------|------|
| SPACOM ELECTRONICS | | |
| 266 No. Mobil Suite III | | |
| Camarillo, Calif. 93010 | | |
| OWN PM 6-74-71 | CKD 52-6/5/74 | APPD |
| SE 125.01 | | |
| 16 BIT DIGITAL DATA SYSTEM | | |

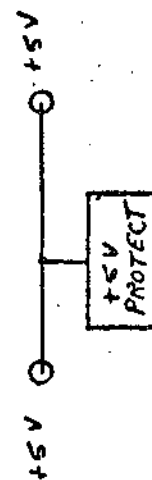
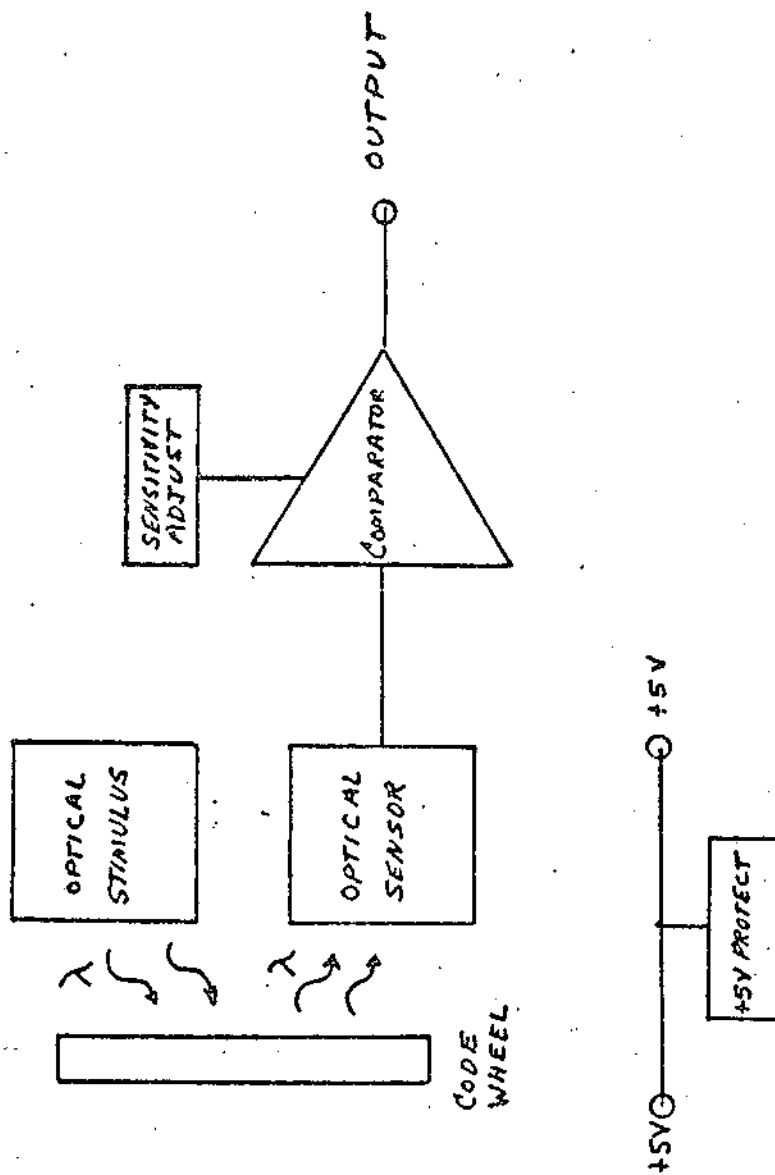
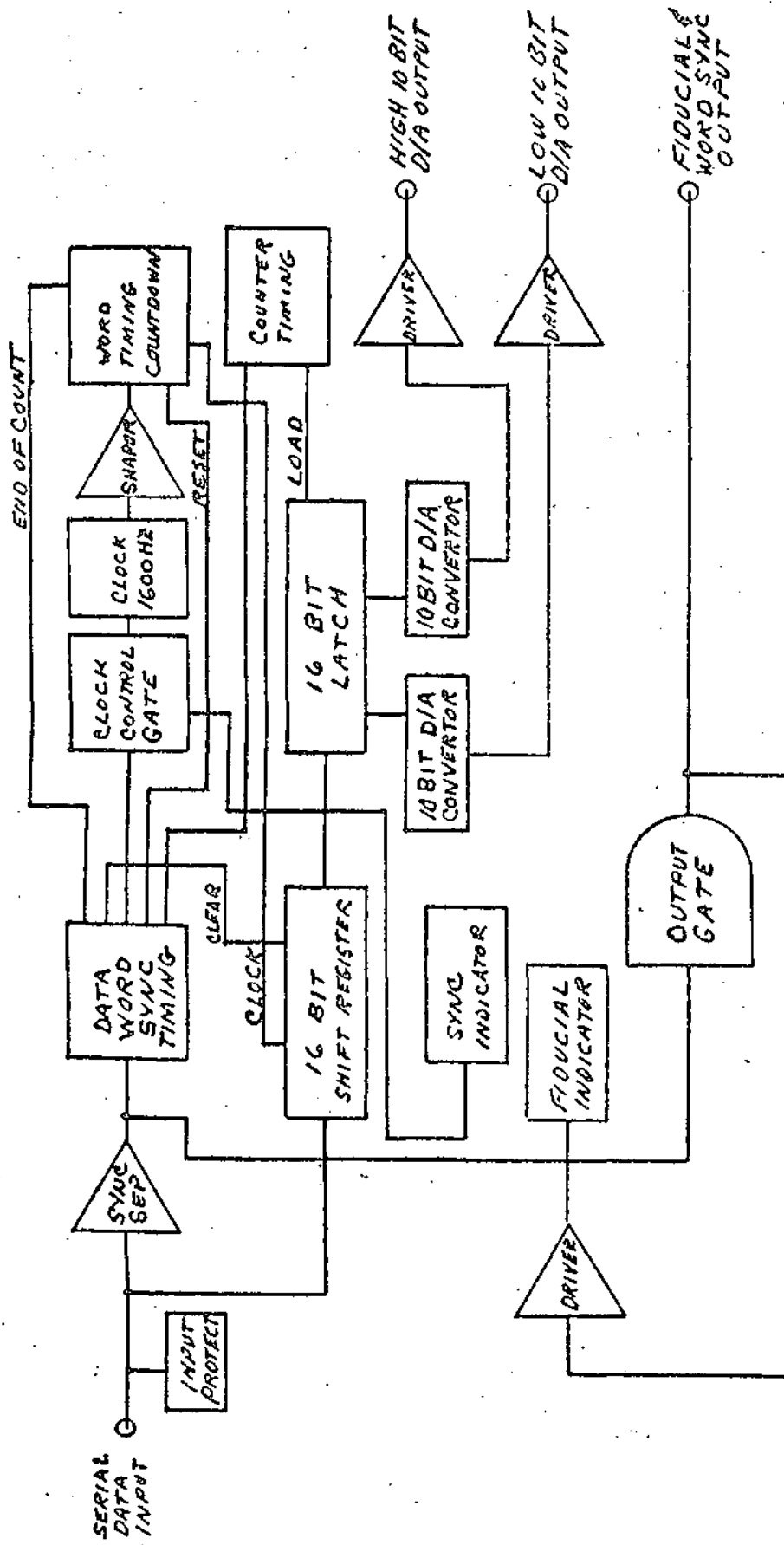


Fig. 3a



| | | |
|-------------------------|-----------------|------|
| SPACOM ELECTRONICS | | |
| 266 No. Mobil Suite III | | |
| Camarillo, Calif. 93010 | | |
| DWN Rev 6-24-71 | CHD 5-2-6/25/71 | APPD |
| SE 126A | | |
| BLOCK DIAGRAM | | |
| OPTICAL FIDUCIAL READER | | |
| | | |

Fig. 3c



+5VOLT
POWER SUPPLY

+15VOLT
POWER SUPPLY

-15VOLT
POWER SUPPLY

| | |
|--|------------------|
| SPACOM ELECTRONICS 266 No. Mobil Suite III Camarillo, Calif. 93010 | |
| OWS 6-25-71 | CKD 6/25/71 APPD |
| SE 226 | |
| BLOCK DIAGRAM | |
| DIGITAL CONVERSION EQUIPMENT | |

2. The B and L diffraction grating was measured in our laboratory and found to have degraded in reflectivity (it had been previously used in our research program). It was over-coated with Al-MgF at GSFC. When remeasured at our laboratory it exhibited close to the reflectivity which was measured when it was originally acquired from B and L.

3. The exit slit mirrors were coated with Al by GSFC. On the recommendation of GSFC no overcoating was applied to these mirrors (which are used at high angles of incidence) in order to avoid optical interference effects. The mirrors were measured at GSFC to have greater than 70% reflectivity in our spectral range. This measurement was confirmed in our laboratory.

4. The EMR 542G photomultiplier tube was checked for quantum efficiency at three wavelengths (1608, 1435 and 1216 A) and found to meet manufacturer's specs but had only 60% of the Q. E. specified for the Apollo UVS.

5. On the basis of the above measurements the instrument sensitivity was found to be about 27 photoelectrons/sec per Rayleigh at 1216 A and 18 pe/sec/Ray at 1608 A.

6. The preprototype calibration was independently checked at these two wavelengths in the Vacuum Optical Bench at Goddard Space Flight Center (Mr. James Diggins). There was only about 10% difference between our laboratory calibration and the VOB check.

7. The VOB calibration also demonstrated that the projected false count rate of 1 pulse per second for the Apollo 17 experiment can be achieved. (This limit is imposed by thermal electrons from the photocathode of the PM tube.) In the VOB the electronics were well shielded from pickup by the vacuum chamber walls, the regulated voltage for the electronics was provided by highly stabilized laboratory supplies and the instrument output was hard wired to the data acquisition system. Thus telemetry RFI, power supply noise and external radiation sources were avoided. Under these conditions the false count level was less than 1 count every two seconds.

IV. Preflight Optical Adjustments

The Ebert mirror and grating optical adjustments required involve rotation of the grating blank and tilting of the grating blank in plane so that the grating rulings are parallel to the axis of rotation of the grating shaft. The Ebert mirror must be adjusted so that the center part of the slits is in the focal plane and so that the center of curvature of the mirror, the horizontal center line of the grating (a line perpendicular to the grating rulings) and the center point of the mirror are on the same line (this line must pass very close to the center point of the grating). These adjustments are independent and can be made with auxiliary optical components. These adjustments can also be made within the instrument with the use of a light source

and a low power microscope. The latter was the method employed on the preprototype spectrometer.

The following optical adjustments were made to the preprototype UVS. They are discussed in detail here because all of the mechanical-optical adjustment means are substantially identical to those provided for the Apollo UVS and all of the adjustment procedures described herein must be made on the Apollo UVS either within the instrument itself or with auxiliary optical fixtures.

1. The slits, grating, and Ebert mirrors were installed. The entrance slit was illuminated with a Hg pen-lamp and a thin wire (20 mil dia.) was placed across the exact center of the slits (parallel to the 2 mm dimension). The grating was rotated so that the central order and the positive and negative first orders of the Hg 4358 line could be observed at the exit slit through a shop microscope. The deviation of the three images of the entrance slit wire shadow from the exit slit wire was noted. The slit plate assembly, which includes the grating mount, was then removed from the main assembly and the grating blank adjusting screws were reset by the indicated amount. The instrument was reassembled and the optical check was repeated. This process was repeated until the positive and negative orders were seen to be equidistant from the center of the exit slit and to both be above or below the center.

2. A portion of the entrance slit jaw image was observed at the exit slit through the shop microscope with the grating set in the central order. The axial distance between this image and the center portion, of the exit slit was measured.

3. The Ebert mirror was removed and the three nylon-tipped pins which determine the mirror position were replaced by new pins whose lengths were calculated to correct the focal error and to center the entrance slit image. The Ebert mirror was then replaced.

4. Steps 1, 2 and 3 above were repeated to refine the final adjustment. The second cycle produced an adequate optical adjustment for the center section of the slits.

5. The images in the central order of the grating of the top and bottom sections of the entrance slit were observed on the shop microscope. The slit plate assembly, which includes the exit slit mirror, was removed and the planes of the exit slit mirrors were adjusted by an appropriate amount by means of changing the length of the three nylon stops that position the mirror plane. The instrument was re-assembled and the adjustment checked. It was found that the first attempt provided adequate correction of the images, which correction is discussed below.

It is a property of grating spectrometers that the spectral image of a straight entrance slit produces a curved image. The spectral error thus produced is given by the equation

$$d\lambda = \lambda \frac{L^2}{F^2}$$

where

$d\lambda$ is the wavelength error

λ is the wavelength

L is the slit length

F is the focal length

For the spectral region about 1400 Å the error is 2.5 Å. Since the spectral dispersion of the instrument is 5 Å per mm, this error amounts to 0.5 mm and requires that the images of the ends of the slit in the central order be displaced 0.5 mm so that in the spectral region 1175 to 1675 Å the curvature error will be minimized. This correction was applied to the preprototype instrument by adjusting the slit mirrors so that the reflected images of the ends of the slit in the central order were displaced $\frac{1}{2}$ mm toward the center line of the instrument.

6. The mirror and the grating had been painted with flat black paint to represent the mirror and grating baffles designed for the Apollo instrument. The grating was visually observed in central order light by placing the eye at the exit slit to determine that the Ebert mirror axis passed sufficiently close to the center of the grating; that is, it was observed that the grating was fully illuminated. This adjustment, if needed, involves modifying the length of the Ebert mirror pins so that the mirror is rotated about an axis perpendicular to the mirror axis

and parallel to the axis of rotation of the grating. It is our general experience that this adjustment need not be made because the manufacturing tolerances are sufficiently accurate.

7. The entrance baffle was installed and the observation described in 6 above was repeated to determine that the entrance baffle was properly aligned and not shadowing the grating. No adjustment was required. If an adjustment had been required, the length of the thermally insulating standoffs that interface the external entrance baffle and the slit plate would have been adjusted to realign the baffle. With the completion of the above procedures the instrument was flight ready with the exception of the precise adjustment of wavelength which is described in the next section.

V. Wavelength Adjustment

The operating spectral range of the UVS is in a region which is not transmitted in air at atmospheric pressure. The adjustment described herein makes it possible to adjust for the operating range without the need for vacuum operation.

The wavelength scan system consists of a motor driven cam which interfaces with the grating shaft by a follower arm which has a pin which fits into the groove in the cam (Fig. 4). The grating shaft is designed so that a long arm can be attached to it external to the spectrometer housing and positioned so that lateral translation of the free

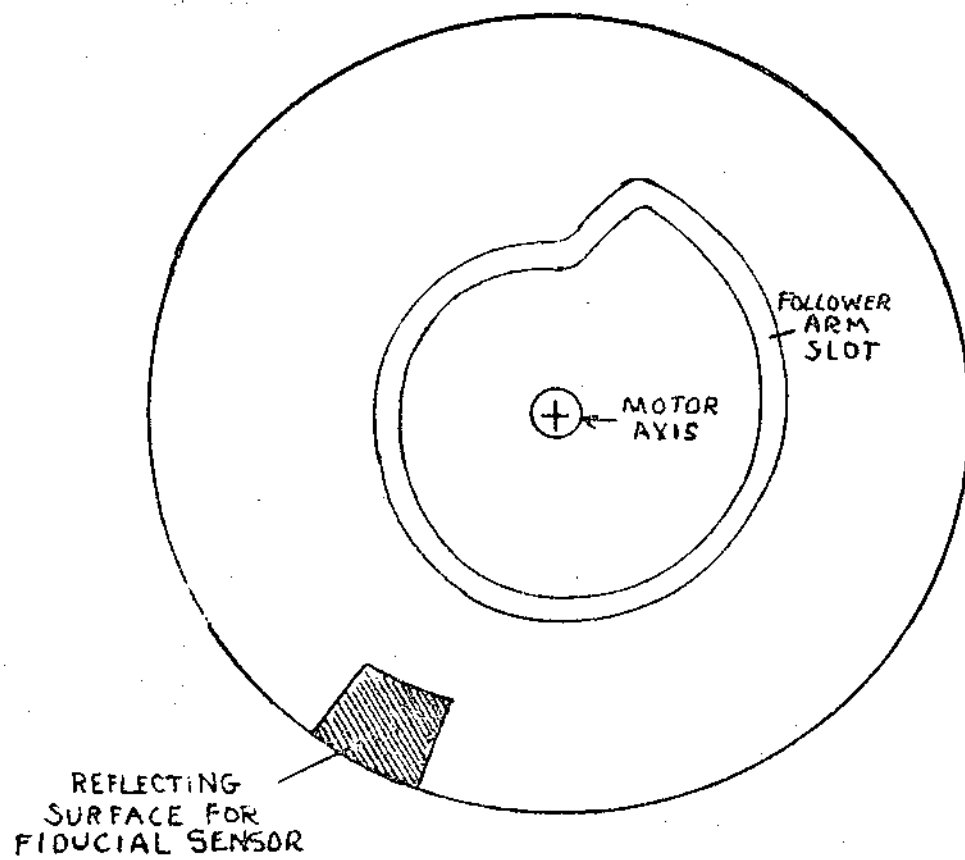


FIG 4- FLIGHT CAM
SCALE=2X

end of the arm rotates the grating. A micrometer caliper is fastened to the main spectrometer housing to measure the position of the arm as shown in Fig. 5. The micrometer was positioned so that its scale was perpendicular to the geometric axis of the main housing, i. e. the Ebert mirror axis.

The cam follower arm was released from the cam and the grating rotated to the central order as indicated by the output of the phototube which was recording the spectrum of a Hg pen-lamp. It should be noted that the position of the grating could be visibly observed through the indicated opening in the main housing to confirm that the central order was being observed. With the grating in the central order the arm was adjusted so that the plane of the micrometer blade passed through the center of the grating shaft as indicated by the dotted line in Fig. 5. The micrometer blade axis of the main housing was then repositioned until the 2537 Hg line was detected and the micrometer travel from zero wavelength to 2537 Å noted. This distance is defined as X_{2537} .

The monochromator wavelength formula is

$$\lambda = 2a \sin \theta \cos \phi \quad (1)$$

where

λ is the wavelength

a is the grating space = $\frac{1}{3.6}$ microns

θ is the angle between the grating normal and the bisector of the incident and diffracted beam

ϕ is the half angle between the incident and diffracted beam

The angle θ is related to the length of the adjustment arm and the distance along the micrometer bar by the formula

$$\sin \theta = \frac{X}{L} \quad (2)$$

where X is the distance the micrometer blade moves from zero order and L is the length of the adjustment arm. Thus the wavelength is given by the formula

$$\lambda(A) = \frac{2 \times 10^4}{3.6} \frac{X}{L} \times .9875$$

$$\lambda(A) = 10 X \quad (\text{where } X \text{ is in mm}) \quad (3)$$

if the adjusting arm is 548.6 mm long and the value of $\cos \phi$ (easily calculable from the known geometry of the mirror and exit slits) has the value .9875.

Thus, to set the wavelength to the start of the scan (1175 Å) the adjusting arm should be moved 117.5 mm to an accuracy of about 0.2 mm (± 2 Å). The reason for using the 2537 line of the Hg lamp is to double check that the geometry is in accordance with equation (3).

With the micrometer set at $X = 117$ mm, the cam was rotated to the starting position and the cam follower arm set in the cam groove locked to the grating shaft. The wavelength adjustment fixture was

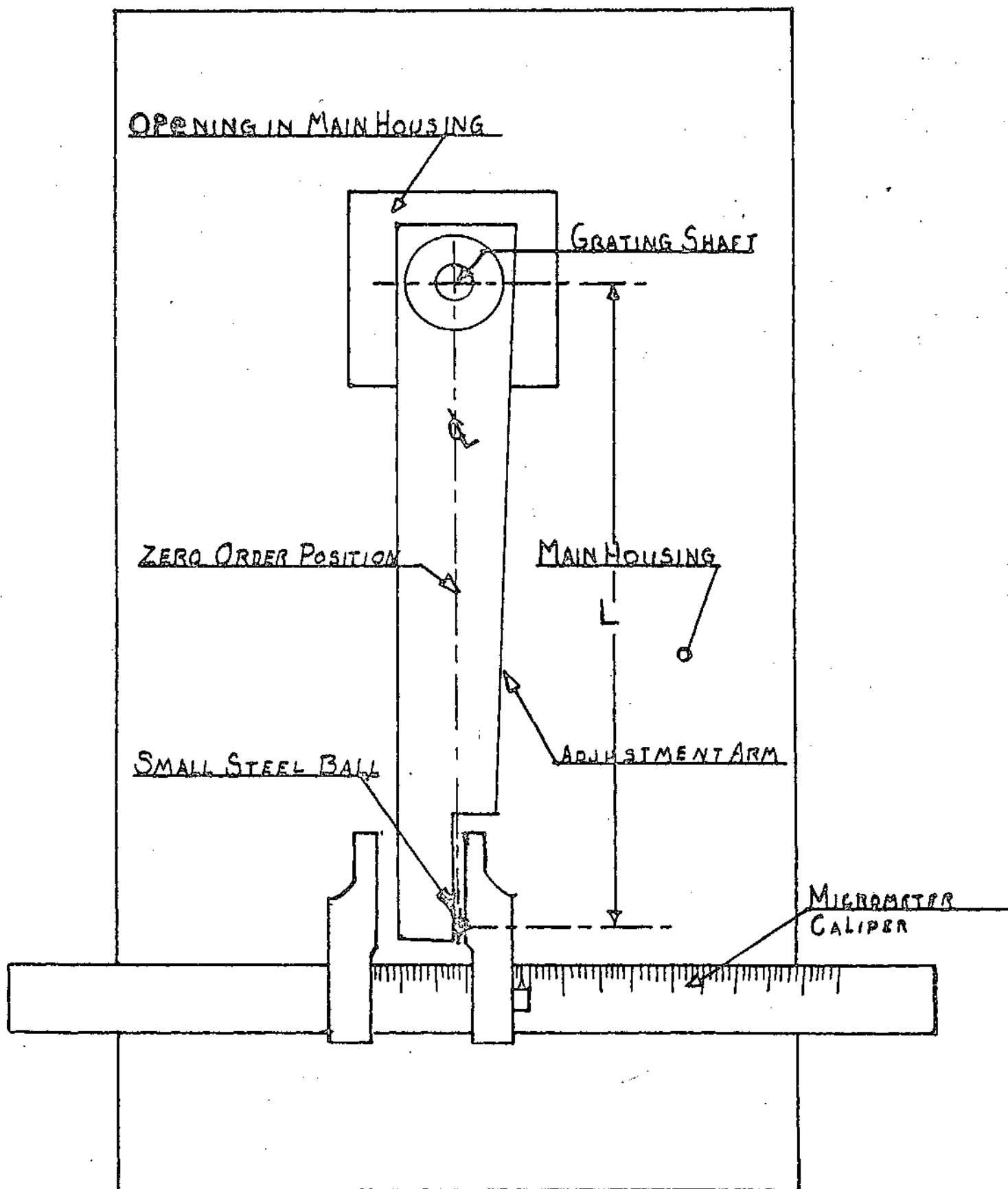


Fig.5 WAVE LENGTH ADJUSTMENT FIXTURE

removed and the cover plate for the opening in the main housing was reinstalled.

The spectrometer was then placed in a vacuum test chamber and the entrance slit illuminated with a UV source. A sample test spectrum thus obtained is shown in Fig. 6, and demonstrates that the adjustment procedure described above was successful. (For the purposes of the rocket experiment we wished to set the starting wavelength at 1170 Å instead of 1175 and achieved this setting to within 1 Å.)

As can be seen in the test spectrum the wavelength scan is not linear in time. The cam was designed so that about half of each scan period was devoted to scanning the regions 1195 to 1245 Å and 1445 to 1495 Å so that better statistics could be obtained on the most likely emission features in the lunar atmosphere, namely, the resonance line of atomic hydrogen at 1216 Å and the resonance line of xenon at 1470 Å. The cam, which was made in conformity with the cam program for the Apollo UVS, was designed to produce 1216 Å between the 17th and 18th $\frac{1}{10}$ second counting period for a starting wavelength of 1170 Å. Fig. 6 shows that this setting was achieved. In this scan range successive counting periods change by about 1.75 Å.

The spectrum of Fig. 6 also demonstrates that the spectral resolution has a value of 10 Å, which is the geometrical limit set by the width of the slit. (Slit width 2 mm, spectral dispersion at the exit slit 5 Å/mm.)

The spectral check thus shows that the optical adjustments described in Section IV were properly executed.

VI. Vibration Checks

The spectrometer was mechanically interfaced with the rocket and given a standard Aerobee 350 three-axis flight acceptance vibration check. The specifications for this test are listed in Appendix C. There was no visible effect on the instrument. During the check visual observations indicated that the free end of the entrance slit baffle moved only very slightly with respect to the adjacent rocket skin, no more than $\frac{1}{8}$ inch. The free end of the baffle was about 40 inches from the mechanical interface points with the rocket structure.

Just before and just after the shake test spectra were obtained in our vacuum facility. There was no observable change in the wavelength position or in the width of the spectral lines, confirming that the required optical rigidity had been achieved.

VII. Baffle Scattering Checks

To properly check the scattering properties of the external entrance slit baffle it would have been necessary to have a large evacuated dark room. As an alternative we checked the baffle at 2537 Å where air is transparent and where scattering from the baffle surfaces can be expected to be at least as great as at shorter wavelengths.

The test was limited by light that was scattered by air. This Rayleigh scattering was so dominant that it was necessary to position the

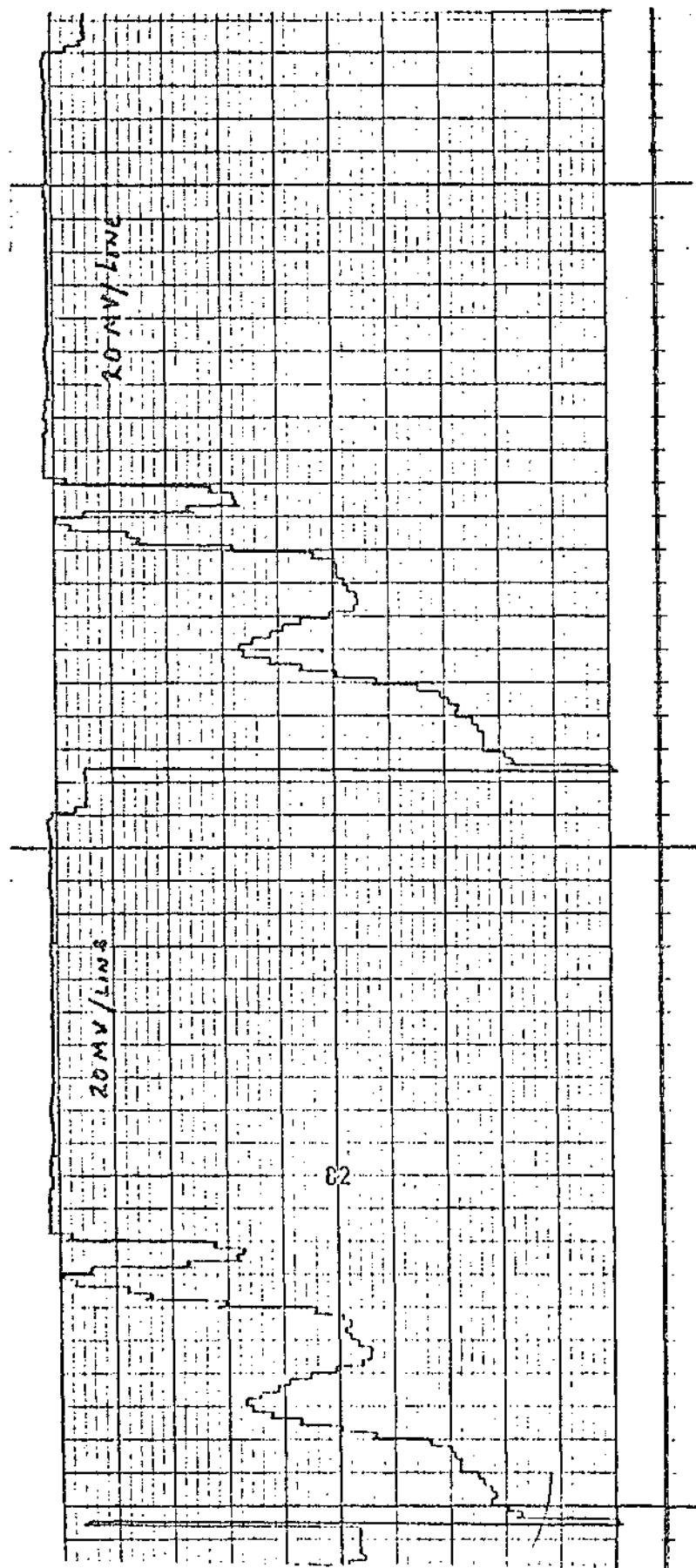


FIG 6
VACUUM CHAMBER
SAMPLE TEST SPECTRUM

light source so that the internal section of the triple sectioned baffle was half illuminated before scattering from the baffle itself was detectable.

Even under this extreme condition the baffle scattering ratio was about 10^6 and was certainly many orders of magnitude less than will obtain with the planned flight geometry and was thus estimated to be adequate for the mission.

VIII. Launch Preparation

The original launch date of June 3 was cancelled because of winds. During the preparation for a June 4 launch an acid spill in the Aerobee tower forced rescheduling for June 10, when the launch occurred.

All preparation of the payload at the launch site was conducted in the clean room located in the preparation area of the Aerobee launch facility. The instruments were installed in the payload portion of the rocket and the nose cone installed in the clean room. When this section of the rocket was removed from the clean room to be mated with the rest of the rocket and to conduct final horizontal checks, pure bone-dry water-pumped nitrogen was purged continuously through the payload section which was isolated from the remainder of the rocket by a pressure bulkhead. For installation in the tower, small leaks in the payload section were sealed with tape and nitrogen flow was continued after tower installation. The break in the nitrogen flow was less than 30 minutes.

During standby in the tower a plastic cover bag was placed over the nose cone and payload section, a rain tent was placed above the rocket (the tower is open to the weather) and the flow of dry nitrogen was increased to about 20 cu. ft. per hour.

The acid spill, which occurred at 2:00 p. m., amounted to 750 lbs. of red fuming nitric acid which did significant damage to the tower, particularly the electric circuitry, and required the tower top water deluge system to be operated for about 2 hours. Due to the loss of power, the rocket could not be removed from the tower until about 9:00 p. m. During this period the nitrogen was purged continuously at an increased rate of about 40 cu ft. /hr.

Visual inspection of the spectrometer in the clean room indicated no damage had occurred, at least no water had entered the payload section of the rocket. The spectrometer was returned to our laboratory at midnight and the next morning the Ebert mirror was removed from the main housing, placed in our vacuum checking facility and compared directly with a spare mirror with which it had previously been compared to about 1% accuracy. This test indicated that there had been no degradation of the optics. The Ebert mirror was replaced. The slit plate was also removed from the main housing to adjust the fiducial marker which had been behaving erratically during the field checks. The instrument was reassembled and placed in our vacuum facility for a wavelength check. The spectral scans thus obtained

were indistinguishable from that shown in Fig. 6 in wavelength position and in spectral resolution.

The above rather harrowing experience demonstrated two important points.

1. The conceptual design of the Apollo UVS is sufficiently rugged to permit disassembly for servicing or checking purposes without disturbing the wavelength setting or the spectral resolution. It demonstrates that the instrument can be transported in a station wagon a distance of 320 miles without degradation in the optical adjustment.

2. The precautions which were taken to protect the instrument from the environment were more than adequate. The seashore environment at Wallops Island is rugged and comparable to that at Cape Canaveral and both represent a danger to the UVS, but neither can compare to the conditions which the preprototype instrument survived.

IX. Flight Results

A. Preliminary Discussion

All of the flight objectives of the Aerobee 350 experiment as they related to the Apollo 17 UVS were fully achieved. Before outlining the results in detail, a limitation which was imposed by the earth's exosphere and an equipment limitation will be discussed.

Even at the peak of the flight, the earth's hydrogen corona was (as expected) a very large signal, of the order of five kiloRayleighs

and represented a constant grating illumination of about 2×10^6 photons per second throughout the spectral scan. Because the grating scattering coefficient has a value of about 10^{-3} , we thus anticipated an unavoidable background signal of about 10^2 photoelectrons/sec against which the in-flight baffle scattering properties could be determined. This limitation was partially overcome by planning the flight geometry so that scattering of solar UV from the baffle could be varied from zero (by having the solar angle at greater than 90° to the optical axis) to about 10 times as much as will be encountered in flight (by having the solar angle at less than 70°). These variations were achieved in flight as a result of rocket precession. With the limitations imposed by Ly α radiation scattered by the grating we would expect to evaluate the solar scattering performance of the baffle which would be representative of Apollo geometry.

For reasons which have not been analyzed, but which are probably due to a combination of sources, the in-flight performance of the electronic system under no light condition was an order of magnitude poorer than the system performance in the VOB reported at the end of Section III. The background noise of about 13 false pulses per second could have originated from telemetry RFI, RFI from other experiments, power supply noise, inherent or fed back from other instruments.

However, this performance did not affect the flight objectives because the Ly α background scattered by the grating was dominant. It should also be noted that the flight was not a test of the specific electronic circuitry which has been designed for the Apollo 17 UVS but was a test of the conceptual design of that system employing commercially available components. The flight result does indicate that the precautions against electrical interference which are proposed for the Apollo 17 UVS electronic system are essential to avoid false backgrounds.

B. Flight Data

1. During the period after rocket burnout (55 seconds) and before nose cone ejection, a random count rate of about 13 pulses per second was observed. The source of this background has not been analyzed.

2. At peak altitude a wavelength independent background count of about 90 per second was observed. This signal is interpreted as being due to geocoronal Ly α scattered by the diffraction grating.

3. During the 140 second period that the rocket was above 305 km, no variation in the background signal was observed. During this period the solar angle with respect to the optical axis varied from 90° to 70° ; thus we estimate that no significant solar signal scattered from the baffle surface will be encountered in the Apollo geometry. This estimate is based on the following calculation:

a. The statistical fluctuation in the 90 photoelectron/second background was about 10 pe/sec.

b. No variation in the background signal in excess of the statistical fluctuation was observed with variation in solar angle.

c. The solar scattering geometry in the Aerobee 350 experiment is estimated to be worse than for the Apollo 17 worse case geometry. Thus, a solar scatter background of a few pe/sec is the largest to be expected under the worse conditions to be encountered in the lunar experiment.

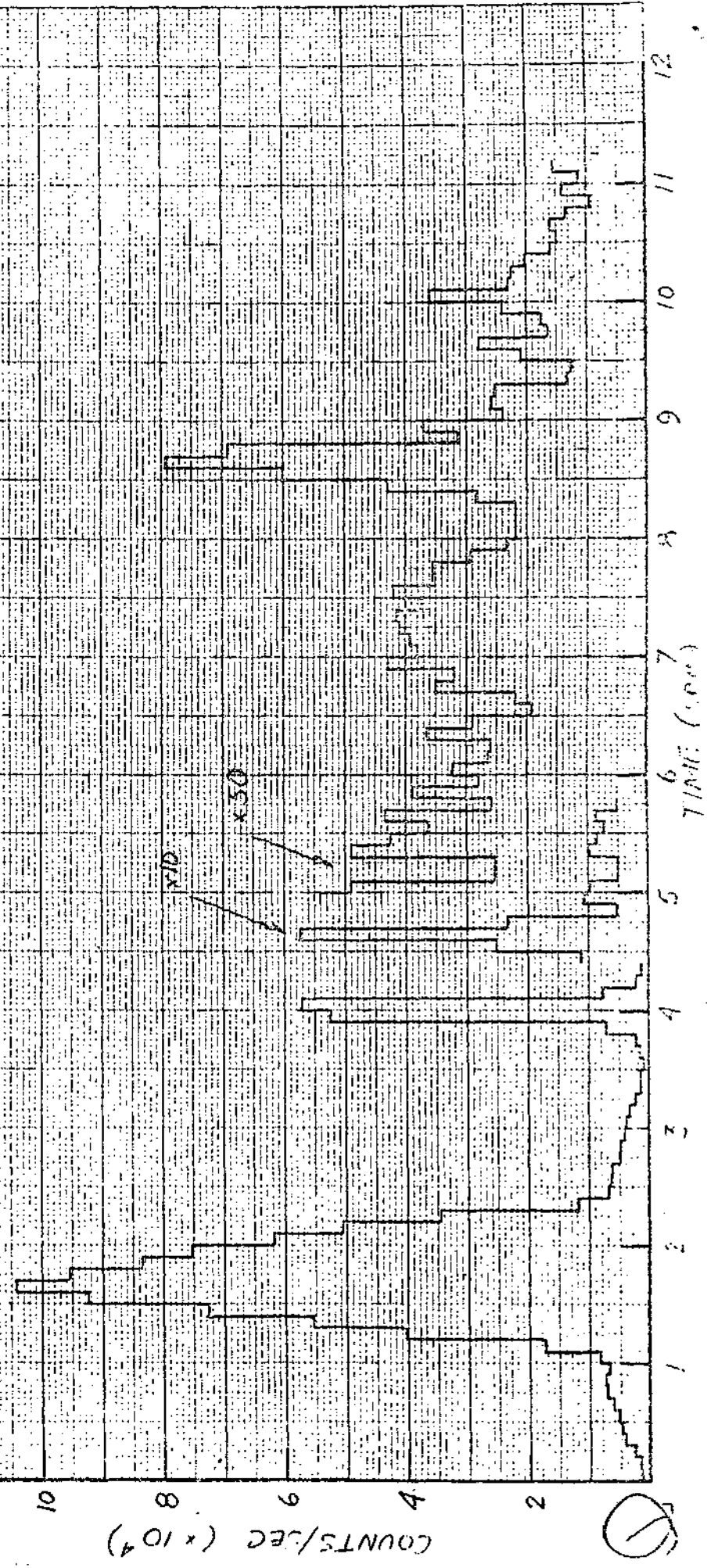
Solar radiation scattered from the illuminated lunar surface will be an important possible source of radiation that the entrance baffle can scatter to the detector. Preliminary analysis indicates that during the most important portion of Mode I and Mode II operation, (i. e. with the spacecraft located on the dark side of the evening and dawn terminator and the optical axis of the UVS directed further into the shadow) the lunar surface scatter signal will be an order of magnitude smaller than the upper limit calculated in c above.

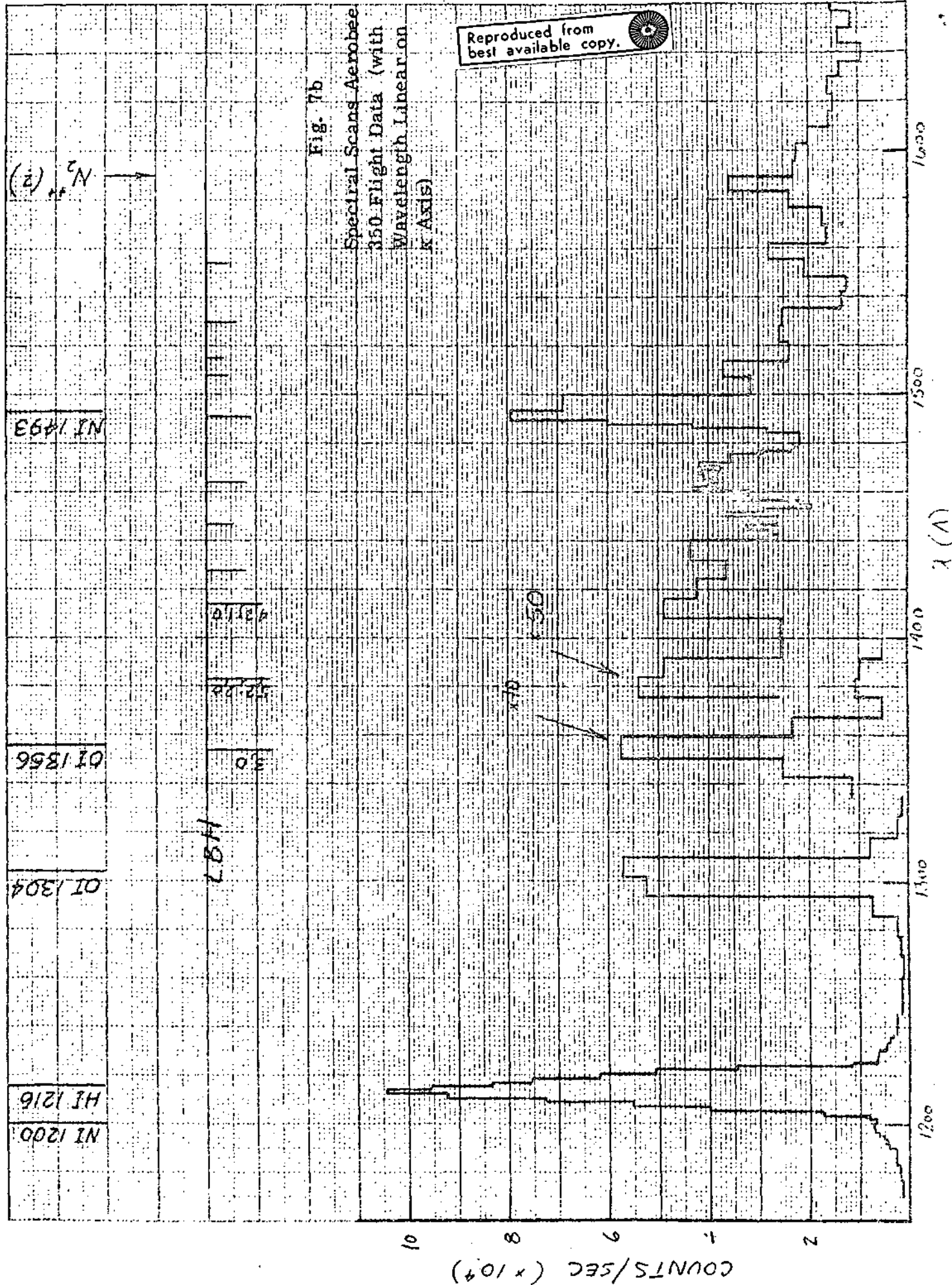
4. During the flight period when the Aerobee UVS was observing twilight ionospheric emissions, many weak emission bands of molecular nitrogen, which have not been previously reported were observed. A summation of the 3 brightest spectra with a preliminary brightness scale is shown in Fig. 7a, where time is linear on the x

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Fig. 7a

Spectral Scans Acrobex 350 Flight
Data (with Time Linear on x Axis)





axis, and Fig. 7b, where wavelength is linear on the x axis. These spectra might be similar to the lunar atmospheric spectra obtained when the landing craft engines are burned.

These flight data demonstrate:

- a. That the high sensitivity observed in laboratory calibration was achieved in flight.
- b. That the spectral resolution is possibly slightly less than laboratory checks indicated would be achieved. The degradation is so small (less than 1 Å) that it cannot be positively evaluated but if real is not significant from the standpoint of the Apollo experiment.
- c. That the wavelength calibration was unchanged throughout the flight and was identical (± 1 Å) to the preflight wavelength check. This can be observed in Fig. 7a where Ly α peaks between the 17th and 18th 1/10 second data point after the fiducial mark. This flight spectrum is identical in wavelength, therefore, with the laboratory test spectrum shown in Fig. 6 and discussed in Section V.
- d. That the Aerobee 350 UVS continued to operate long after the beginning of the aerodynamic shock of reentry. Signal was finally lost due to telemetry failure, which occurred because of reentry shock. Thus, the instrument performed in a shock environment far more severe than the preflight environment checks imposed.

X. Recommendations

Based on our experience with the Aerobee 350 UVS, it is the writer's firm conclusion that the engineering details of the proposed Apollo 17 UVS which will be presented at the critical design review will make it possible to produce an instrument which can fulfill the scientific mission which has been proposed. No flaw in electronics, optics, or mechanics has been detected in an instrument which is a remarkably close model and which has been subjected to realistic tests, realistic environments and which has made significant space measurement.

Preliminary analysis of the flight data suggests that small changes in the cam program might be advantageous from the standpoint of maximizing the Apollo 17 flight information. The Aerobee 350 cam scanned two 50 Å regions at about 17.5 Å/sec and the remaining 400 Å at about 64 Å/sec. The fast rate thus gave about three 0.1 sec measurements of a spectral feature (the full width of the bottom of the triangular signal being 20 Å as determined from flight data). We are currently considering decreasing the high speed scan rate slightly and increasing the slow speed somewhat. A detailed analysis is in progress. This change, if decided upon, will have a minor effect on the engineering program. It is recommended that the detailed cam design be delayed for a few weeks until the above analysis is complete.